

# Thorium molten salt reactors —Restart development—

R. W. Moir

Vallecitos Molten Salt Research

Livermore, CA 94550

[RMoir@Pacbell.net](mailto:RMoir@Pacbell.net)

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# Outline of talk

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- What—restart MSR R&D
- Why—Lower cost, less wastes, extend resource
- Plan—Mission, customer/funding, tasks
- Results
- Conclusion

# Recommendations for a restart of molten salt reactor development

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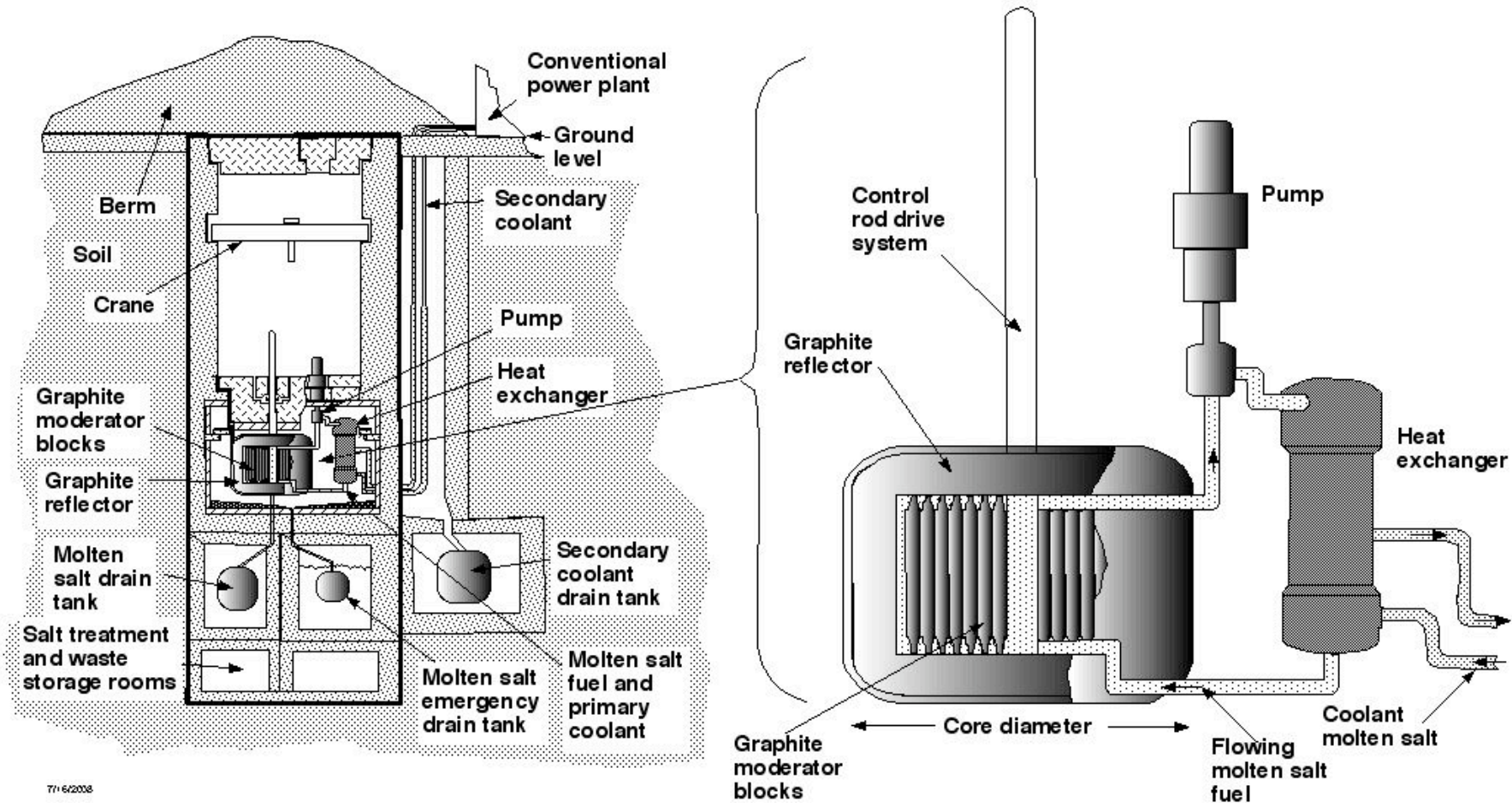
[www.elsevier.com/locate/enconman](http://www.elsevier.com/locate/enconman)

## Recommendations for a restart of molten salt reactor development

R.W. Moir\*

*Vallecitos Molten Salt Research, 607 E. Vallecitos Road, Livermore, CA 94550, United States*

# Themes: thorium, underground, beat coal costs



R. W. Moir and E. Teller, "Thorium-fueled, underground power plant based on molten salt technology," *Nuclear Technology* **151** (2005) 334-340.

## The MSR is predicted to be more economical than coal based on 1978 assessments

Economic comparisons of cost of electricity in units of \$/MWh, 2000\$

	MSR, 20% enriched		MSR, 100% enriched		PWR	Coal
Capital	20.1	Th-20%U233	20.1	Th-U233	20.7	15.8
O&M	5.8	80%U238	5.8	cycle	11.3	8.0
Fuel	11.1	cycle	4.0		7.4	17.2
Waste disposal	1.0		1.0		1.0	0.9
Decomposition	0.4		0.4		0.7	–
Total	38.4		31.3		41.1	41.9

**Needs updated comparison, especially with coal sequestration included.**

R. W. Moir, “Cost of electricity from molten salt reactors,” *Nuclear Technology* **138** (2002) 93-95.

# Missions

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1—Burn (fission) actinide wastes from LWRs in the MSR

- Each MSR burns 1000 kg per year @ 1 GWe
- Each LWR produces Pu (300 kg/GWe•y), Np+Am+Cm (30 kg/GWe•y)

**Tap into waste management fund**

V. Ignatiev et al., “Progress in Development of Li, Be, Na/F Molten Salt Actinide Recycler & Transmuter Concept,” Proceedings of ICAPP '07 Nice, France, May 13-18, 2007, paper 7548.

2—Use thorium, breed U-233, expand to >10 TWe by 2100

3—Small power plants for special purposes, 10 MWe?

## Who is the customer?

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- Government—DOE's Nuclear Energy, Waste Management [Yucca] Fund, National Nuclear Security Administration
- Utilities
- Foreign governments, China, India,....
- Navy, Army—small power plants/*reduces NRC involvement*
- Non-Government Organizations, Google? Microsoft?....

Need “market pull”



# Bill Gates is the principal owner of TerraPower, p30



- Gates is supporting plutonium fast reactor development.
- Google might be interested in supporting thorium molten salt reactor development as an alternative
- A start-up would be timely



# Elements of a plan to restart MSR development—fast track

Furukawa proposed miniFUJI 7 MWe with Russia about ten years ago

- \$300 k —write a proposal
  - \$3 M —develop R&D plan and preliminary design of 10 MWe unit
  - \$30 M —design 10 MWe unit
  - \$300 M—build 10 MWe unit
    - Snezhinsk, Chelyabinsk site was approve by Russia
- 
- Cost escalation + parallel R&D
  - Lead organization?—it used to be ORNL
  - Who to fund?—it used to be US government/DOE

## What R&D is needed?

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- Study and select options and issues:
  - Fuel with wastes from LWRs or U235 or U233
  - Fast vs thermal neutrons
  - Thorium vs Plutonium
  - One fluid vs two fluid versions---> what materials?
  - Graphite damage
  - Separation methods, chemical, mass separator, ...
  - Proliferation risk/U232 spiking/safeguarding

**Restart by designing and building 10 MWe “Learner”  
plant ----->Where?**

# We need to choose between alternatives: 1 vs 2 fluids, graphite vs no graphite

## One-fluid with graphite design

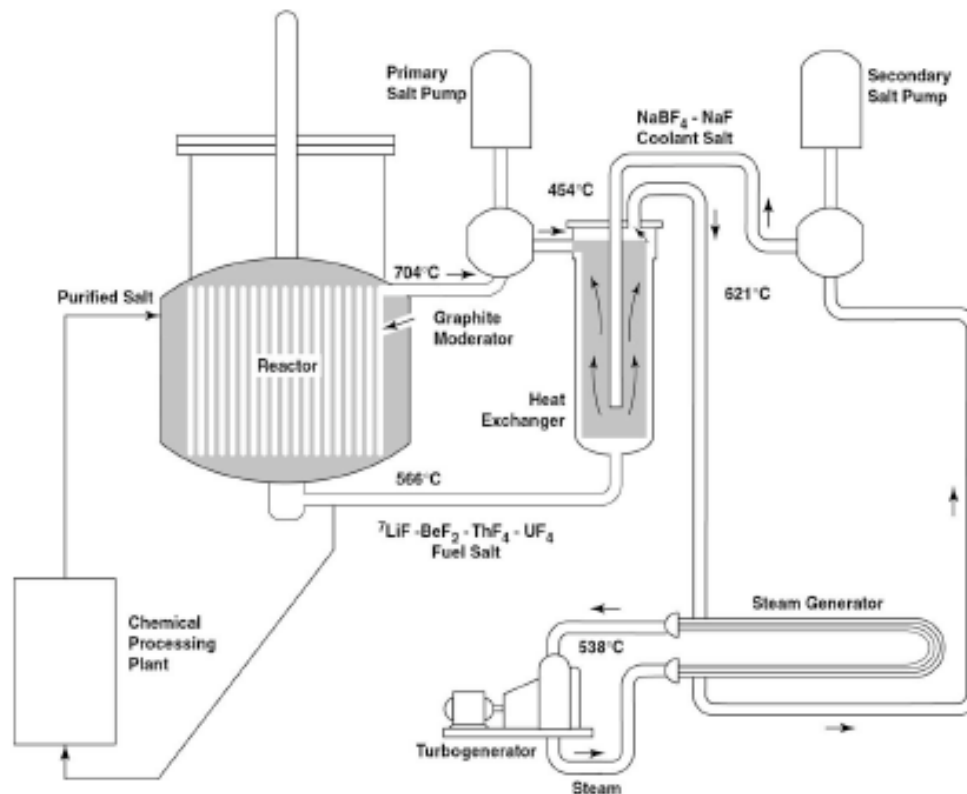
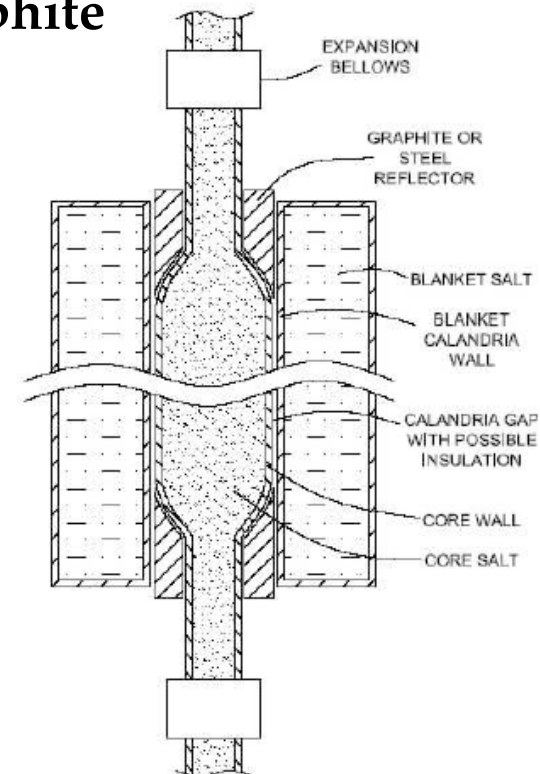


Figure 3 The 1970s Single Fluid, graphite moderated Molten Salt Breeder Reactor. Breeding Ratio of 1.06, with a specific inventory of 1500 kg/GW(e). Reproduced from ORNL 4812

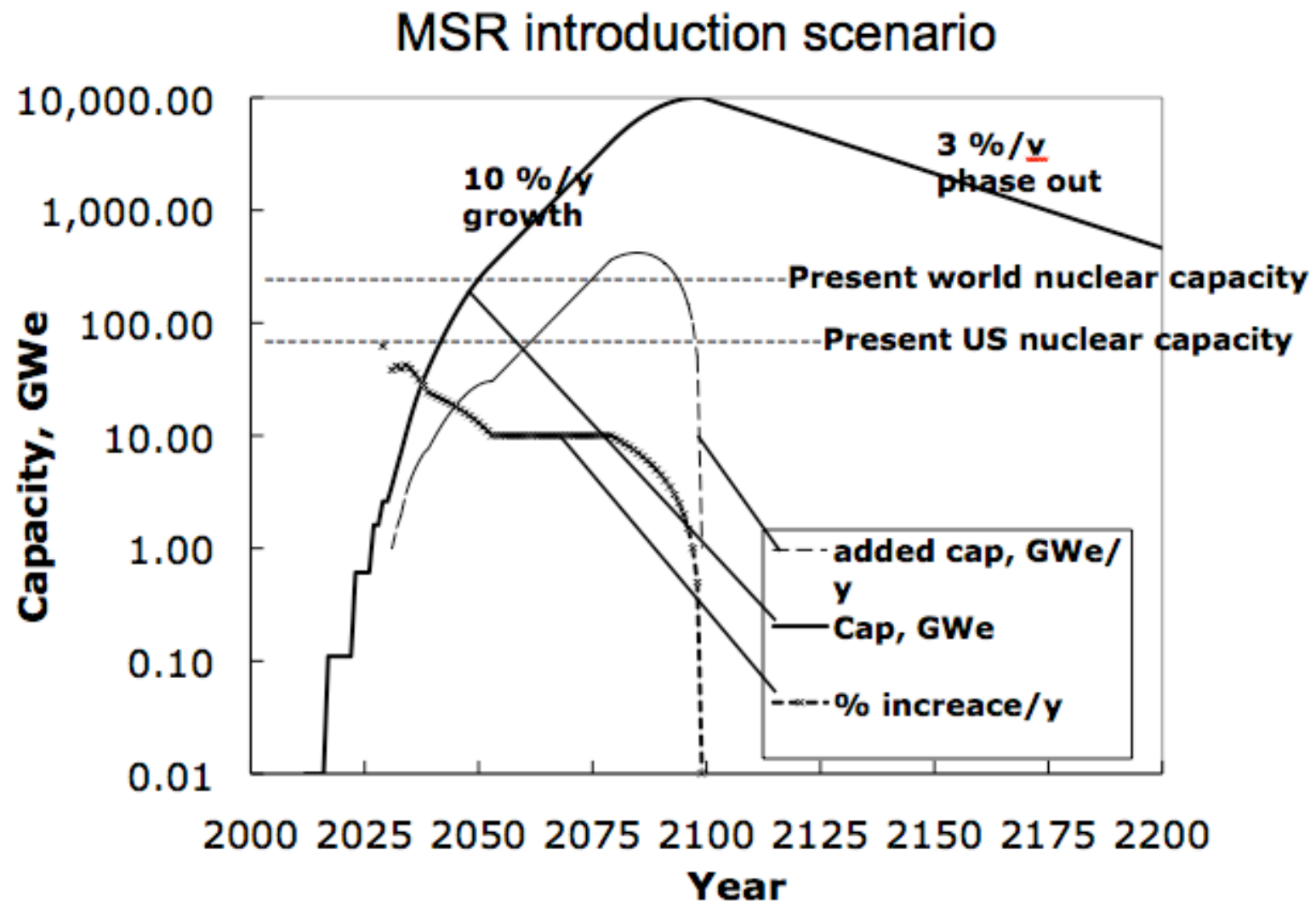
## David LeBlanc's two-fluid design, ICONE17 July 11-16, 2009, Brussels, with or without graphite



**Separator material damage**

**Limited power per unit**

If we start MSR R&D&Deployment by 2010—doubling of nuclear power by 2050 but twenty five-fold increase by 2100.

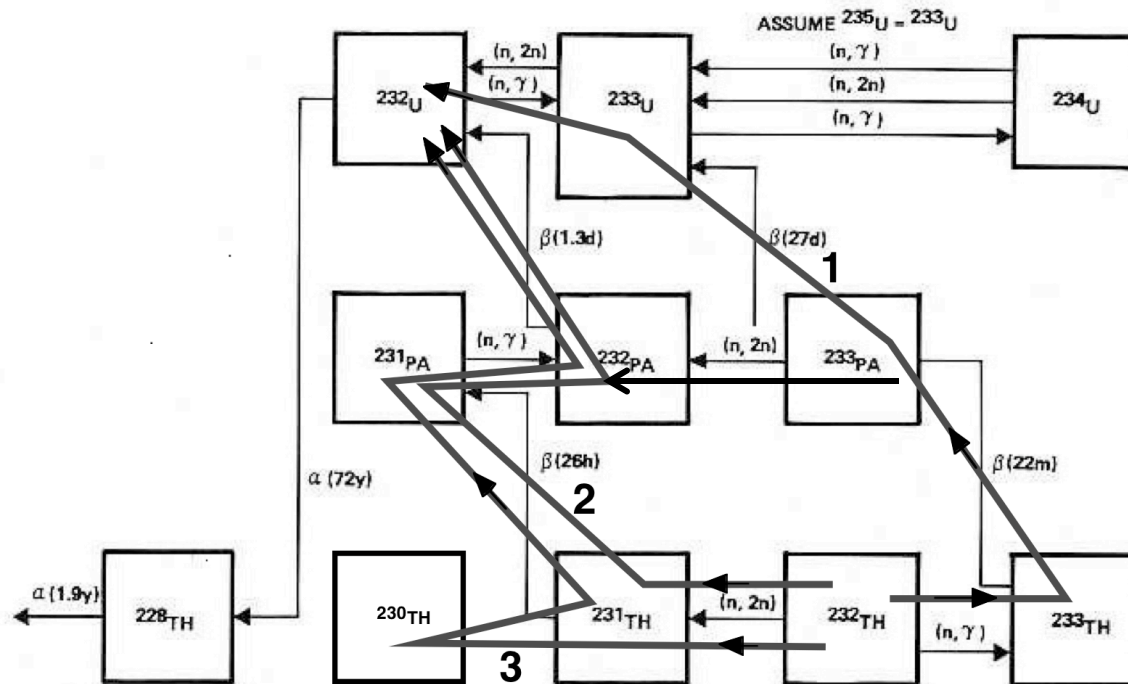


# Conclusions

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- The thorium molten salt reactor is ready for a start-up entrepreneur to develop a program to build a “learner”/pilot 10 MWe prototype
- Burn up LWR wastes in near term
- Use thorium to build >10 TWe by year 2100
- Major contributor to solving fission waste problem and climate CO<sub>2</sub> reduction

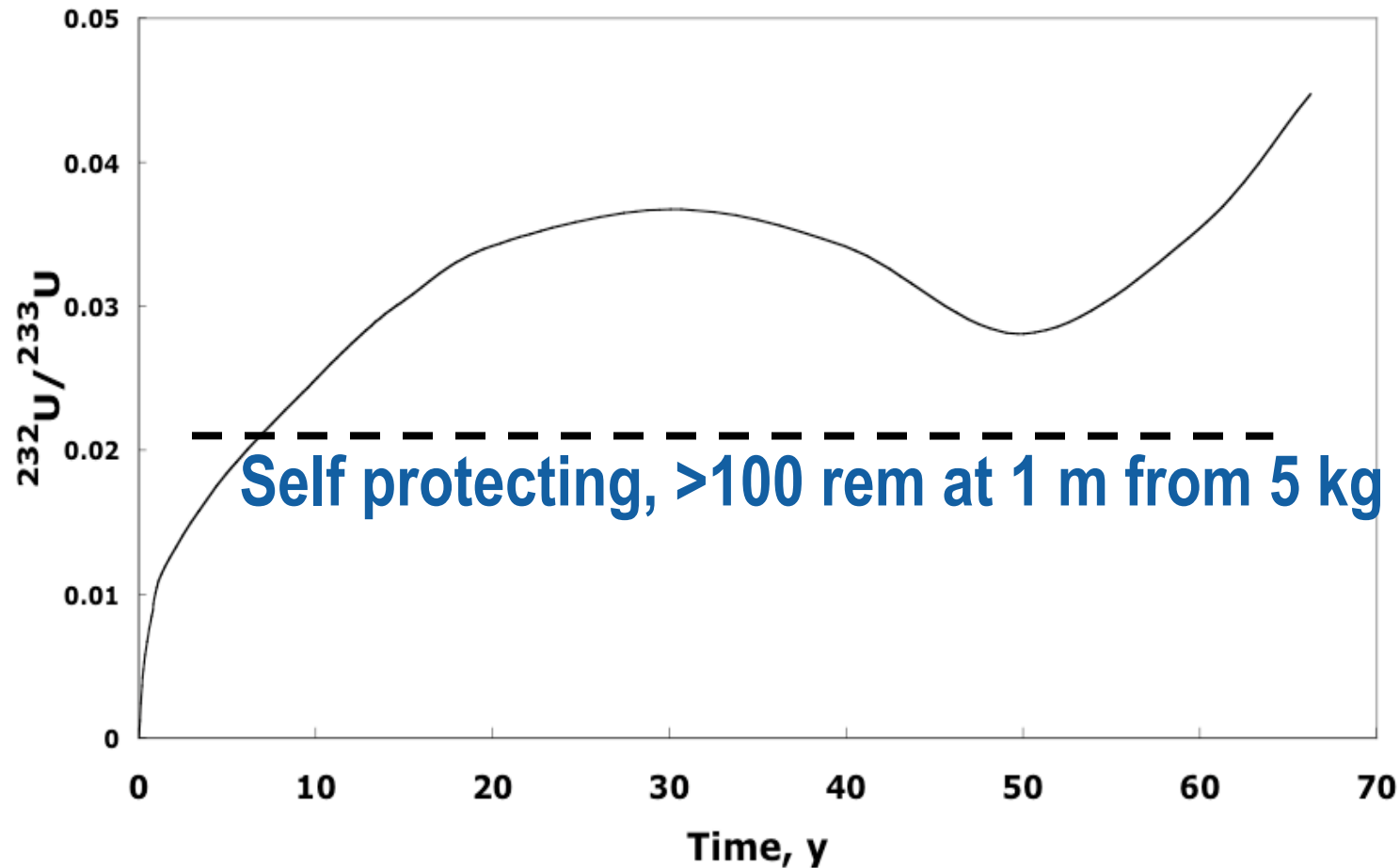
# Neutron reaction paths leading to $^{232}\text{U}$ production



- Maintaining  $^{232}\text{U}/^{233}\text{U} > 2.4\%$  aids non-proliferation: J. Kang and F. N. von Hippel, "U-232 and the proliferation resistance of U-233 in spent fuel," *Science & Global Security*, **9** (2001) 1-32.
- Pa-231 ( $T_{1/2} = 33,000$  y) becomes primary source of U-232.
- Avoid Pa sequestration if possible.

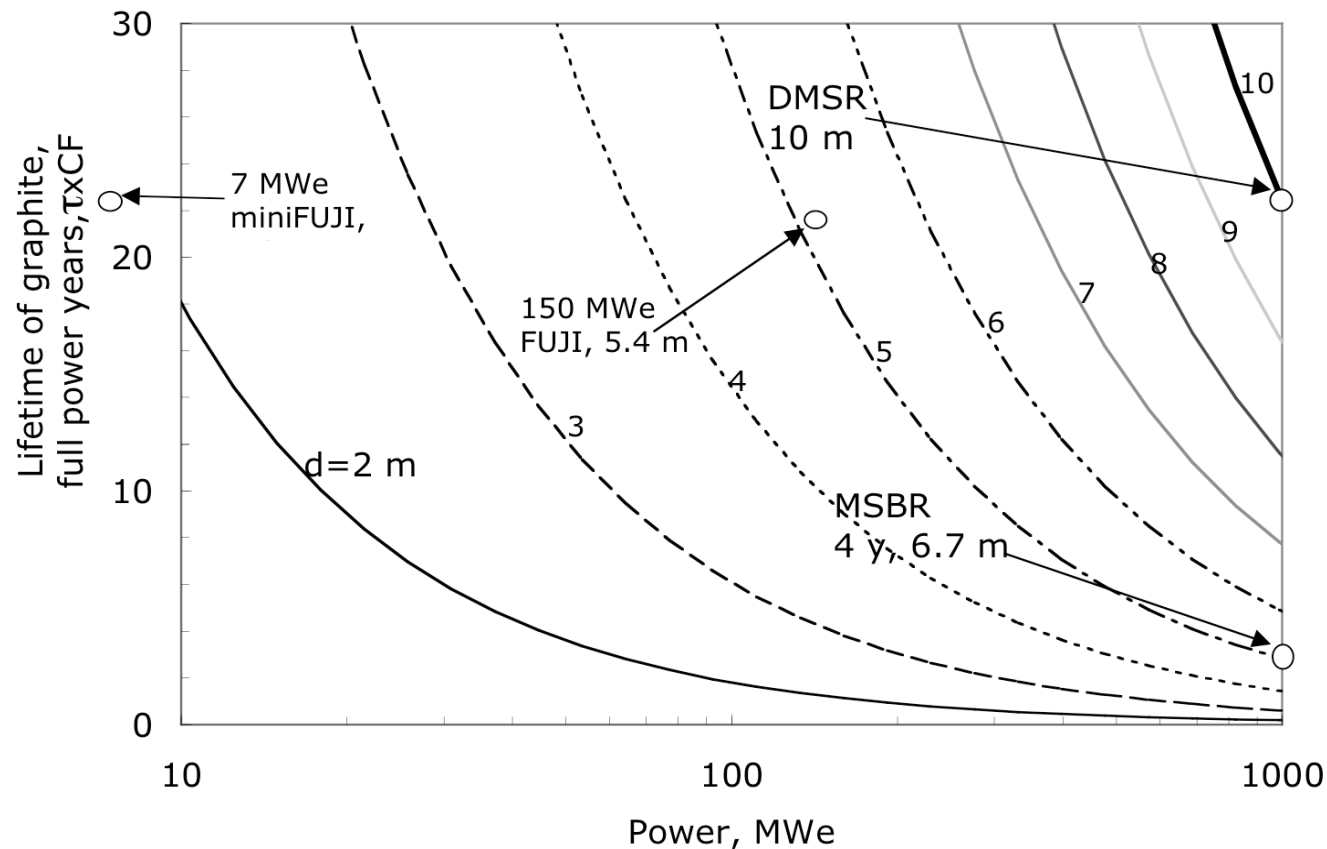


## $^{232}\text{U}/^{233}\text{U}$ ratio versus burn time for a breed/burn example aids non-proliferation.



Could add  $^{238}\text{U}$  for non-proliferation also.

# The core graphite lifetime is related to power and core size.



For more information see: Kazuo Furukawa, Kazuto Arakawa, L. Berrin Erbay, Yasuhiko Ito, Yoshio Kato, Hanna Kiyavitskaya, Alfred Lecocq, Koshi Mitachi, Ralph Moir, Hiroo Numata, J. Paul Pleasant, Yuzuru Sato, Yoichiro Shimazu, Vadim A. Simonenco, Din Dayal Sood, Carlos Urban, Ritsuo Yoshioka, "A Road Map for the Realization of Global-scale Thorium Breeding Fuel Cycle By Single Molten-Fluoride Flow, Molten salt reactor for sustainable nuclear power-MSR FUJI," *Energy Conversion and Management*, 49 (2008) 1832–1848.